The Influence of Element Formulation on Seated Pressure Predictions in a Human Body Model.

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I. INTRODUCTION

Human Body Models (HBMs) are widely used in injury biomechanics to evaluate occupant response under dynamic loading conditions such as vehicle crashes. Prior to dynamic simulation, quasi-static gravity settling is performed to establish initial contact conditions between the body and the seat. These initial conditions influence load transfer and subsequent kinematic and kinetic response. Previous work has shown that settling behaviour and body-to-seat coupling influence subsequent dynamic response [1]. Validation efforts have largely focused on overall model behaviour, with limited evaluation of localised contact pressure and soft tissue deformation. Experimental studies using pressure mapping systems, such as those by XSensor (Calgary, Canada), and imaging techniques including MRI, have shown that seated load is primarily supported in the ischial region [2]. However, discrepancies between simulated and experimental pressure distributions remain. Soft tissue representation plays a critical role in load transfer and deformation, and previous studies have demonstrated that element formulation can influence predicted biomechanical response [3]. The objective of this study is to develop a contact-pressure-based method to evaluate the influence of element formulation on quasi-static settling behaviour by comparing simulated contact force distributions to experimental measurements under identical boundary conditions.

II. METHODS

A previous experimental study collected pressure data to quantify loading of the buttocks and posterior thigh under load. Data were collected under IRB approval (#00109011) at Wake Forest School of Medicine from eight healthy male participants (ages 18–44 years, BMI 18.1–29.9 kg/m²). Subjects were positioned in a standardised 90-90-90 seated posture, as shown in Figure 1. Pressure data were collected using an XSensor (LX210:40.40.02) pressure mat with a 40 × 40 sensing-point grid. The experimental pressure heat maps were aligned using Fast Fourier Transform (FFT)-based two-dimensional cross-correlation to correct for spatial offsets and were averaged to obtain a representative pressure distribution.

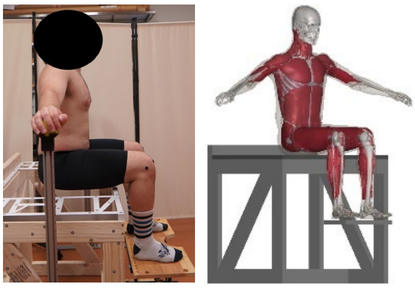

Fig. 1: Experimental and Computational 90-90-90 Seated Setup.

A computational study was conducted by mimicking the experimental set up in a virtual environment using the Global Human Body Model Consortium (GHBMC) 50th percentile male model (M50-O v6.2.1). Two model configurations were evaluated: a baseline configuration and a modified configuration in which element formulation was adjusted within the adipose tissue. A rigid acrylic seat and footrest were defined to replicate experimental conditions, with spatial resolution matched to the pressure sensing system. Gravitational settling was applied for 1000 ms to ensure stable contact conditions. Boundary constraints were applied at the knees, feet, hands, and along the spine (C1–T12) to maintain posture and prevent non-physiological motion during settling. Translational motion in the X and Y directions was constrained at these locations to limit horizontal sliding on the seat, while translation in the Z direction was left unconstrained to allow vertical settling under gravity. A corresponding segment set of 1600 individual contact force transducers, each measuring 161 mm^2, were implemented to match the sensor grid, enabling direct one-to-one comparison between simulation and experiment pressure mat. Due to nodal force contributions from multiple connected elements, contact forces were normalised to avoid double counting prior to mapping. The mesh, geometry, and material properties were held constant between configurations. Element formulation was modified for existing elements within the gluteal and thigh soft tissue regions (e.g., from ELFORM=1 to ELFORM=-1 for hexahedral elements and to ELFORM=13 for tetrahedral elements), isolating the effect of formulation on model response. Element formulation has been shown to influence deformation behaviour and numerical stability in soft tissue simulations [3]. Pressure data

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were recorded in pounds per square inch (PSI), with sensor saturation occurring at 16 psi. In cases where saturation occurred, peak pressures were estimated using a Gaussian-based reconstruction applied along the row-wise pressure distribution. Sensor saturation affected less than 0.4% of the sensing points in cases where peak values were observed. Weight distribution and peak pressure location were used as primary evaluation metrics.

III. INITIAL FINDINGS

Experimental pressure data showed peak loading localised in the ischial region, consistent with expected anatomical load-bearing behaviour. In the baseline model, peak loading was not concentrated at the ischial region but instead occurred in a more distributed fashion, indicating a discrepancy in load transfer and contact behaviour. Following modification of the element formulation, the spatial distribution of load shifted, with peak loading occurring in the ischial region, similar to the subject average.

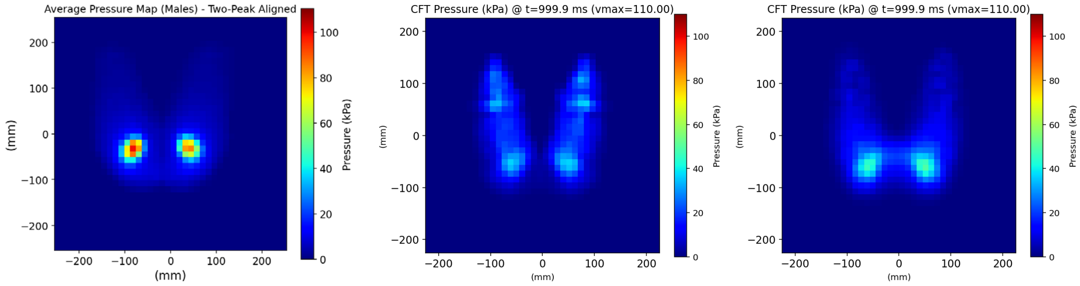

Fig. 2: Male average experimental pressure distribution (left), baseline M50-O model (middle), and modified element formulation model (right).

Figure 2 compares the average experimental pressure distribution, baseline model, and modified model. The baseline model exhibits a more distal load distribution, while the modified formulation shifts load proximally toward the ischial region. While overall force magnitudes remained comparable between configurations, the location of peak loading was notably affected by the element formulation. Additional objective metrics showed that the element formulation change reduced relative posterior pelvic tilt by 0.441° while the acetabulum-to-acrylic seat Z-distance decreased by 0.135 mm, suggesting slightly greater vertical pelvic settling.

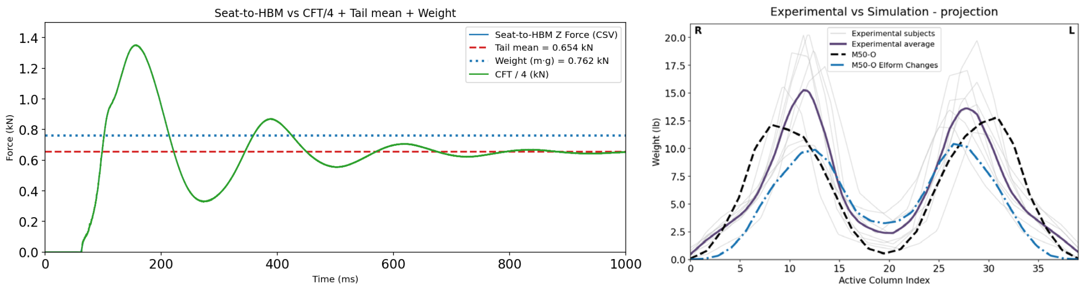

Fig. 3: Seat-to-HBM force validation, and load distribution across the seating surface.

Figure 3 shows seat-to-HBM contact force and total reaction force convergence to a stable value consistent with system weight, with reduced magnitude due to load sharing between the seat and footrest. Column-wise summed force distributions (load per active column) capture the left-to-right load distribution across the seating surface.

IV. DISCUSSION

The results demonstrate that element formulation influences the spatial distribution of contact pressure during quasi-static settling. With mesh and material properties held constant, changes in formulation altered deformation behaviour and load transfer, resulting in differences in pressure localisation. The baseline configuration produced a more even, bimodal load distribution (lower trough in Fig. 3). The modified formulation improved agreement with experimental data by shifting load toward the anatomically expected load-bearing region. These findings highlight the importance of evaluating localised response metrics when validating HBMs. Reliance on global measures alone may overlook discrepancies in contact mechanics and soft tissue behaviour, critical for accurately representing human-seat interaction. Future work will investigate combined effects of adipose material models [4] and element formulation, and extend validation through comparison with morphological changes in the thighs during seating.

V. REFERENCES

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